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Study of Alfvén Eigenmodes in the NBI Heated Plasmas of the CHS Heliotron/Torsatron

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Abstract

During NBI heating, coherent magnetic fluctuations with relatively high frequencies (> 80 kHz) are observed in CHS plasmas. For various plasma parameters (toroidal field, electron density and ion mass species), the observed mode frequency is proportional to the Alfvén velocity, and agrees well with the predicted toroidal Alfvén eigenmode (TAE) frequency. This mode is not observed in ECH plasmas. These data suggest that the observed mode is the TAE mode excited by energetic ions produced during NBI heating.

Keywords:

Alfvén Eigenmodes, helical device, magnetic fluctuations, energetic ion, magnetic shear, neutral beam injection

1. Introduction

In a fusion reactor, it is predicted that Alfvén Eigenmodes (AE), such as toroidicity-induced Alfvén Eigenmodes (TAE), driven by energetic alpha particles could expel the energetic particles before thermalization. Therefore, AEs are intensively studied in large tokamaks, and are observed during NBI and/or ICRF heating [1-3]. This issue is also important in helical systems such as stellarator and heliotron/torsatron. In the magnetic shearless stellarator W7-AS, global Alfvén eigenmodes (GAE) are observed as a result of the magnetic configuration. On the other hand, CHS heliotron/torsatron has relatively high magnetic shear which is comparable to the tokamak but has opposite sign ($q'=(2\pi/\iota)'<0$). In CHS, TAE may be excited by the presence of energetic ions, rather than GAE. In NBI heated plasmas of CHS coherent magnetic fluctuations are observed in the TAE frequency range. In this paper characteristics of the mode activities are discussed experimentally in various discharge conditions.

2. Experimental Condition and Result

This experimental campaign is carried out in NBI heated hydrogen and deuterium plasmas on the following discharge conditions; toroidal magnetic field ($0.7 < B_t < 1.8$ T), electron density ($0.5 < n_e < 3.0\times10^{19}$ m^{-3}) and NBI power ($0.3 < P_{NBI} < 0.7$ MW) in the CHS heliotron/torsatron. For comparison, we also study ECH plasmas. The principal fluctuation diagnostics are magnetic probe arrays and soft X-ray detector array. One of the former consists of six sets of coils installed inside a thin stainless pipe protected by a carbon sleeve containing 20 % Boron to detect poloidal and radial field fluctuations, and can insert into the plasma ($r/a > 0.8$) without serious disturbance. Four sets of

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magnetic probe arrays are arranged in the toroidal direction. Each probe array consists of 3 coils for toroidal, poloidal and radial field measurements. A 20 channel soft X-ray detector array is installed on the vertical viewing port. Each Signal from both diagnostics is acquired through an antialiasing filter with 300 kHz cut off frequency, and digitized typically at 500 kHz sample rate.

Figure 1 shows a typical time evolution of NBI heated plasma and frequency spectral power of magnetic fluctuations in the TAE frequency range. In this shot the toroidal magnetic field is B_t=0.9 T and hydrogen neutral beam with 34 keV energy (absorbed power $P_{NBI}\sim 0.6$ MW) is injected tangentially in the co-direction. The frequency of the mode is relatively high (>100 kHz) and becomes lower with increase in electron density. It can be distinguished from usual pressure driven modes (<40 kHz). Figure 2 shows comparison of measured frequencies with the theoretical TAE frequencies $f_{TAE}=V_A/4\pi qR_0$, where V_A is Alfvén velocity $V_A=B/(n_i m_i \mu_0)^{1/2}$ and $q=3$ is assumed in the central region of the plasma. Data points are obtained on the

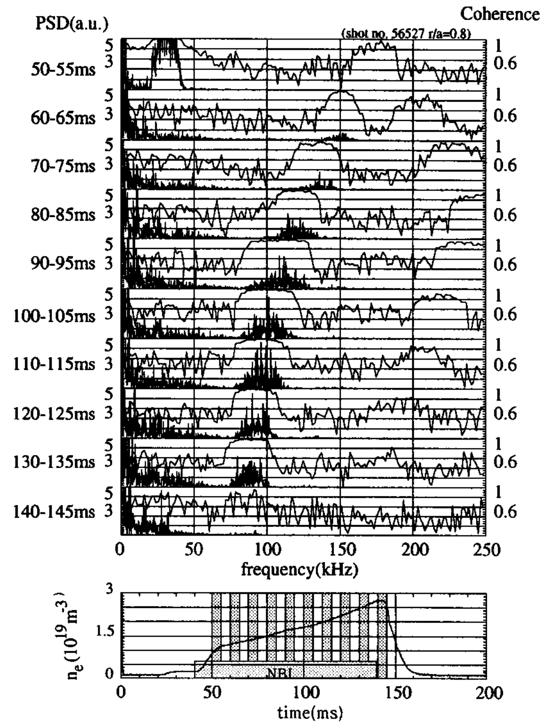

Fig. 1 Time evolution of typical frequency spectra of magnetic fluctuations and line averaged electron density, where B_t= 0.9 T and NBI co-injected with 34 keV energy. The absorbed NBI power reaches up to 0.6 MW.

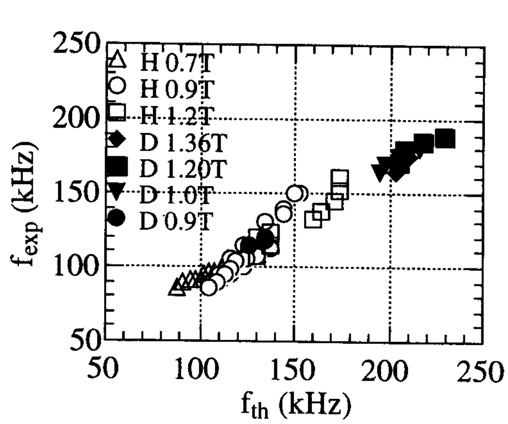

Fig. 2 Comparison of measured frequencies f_{exp} with theoretical TAE frequencies f_{th}, where q=3 is assumed in the central region of the plasma, and electron density at the plasma center is employed.

discharge conditions; $0.7 < B_t < 1.5$ T, $0.5 < n_e < 3\times10^{19}$ m^{-3} for H and D plasmas. The observed mode frequencies agree consistently with the TAE mode frequencies, but are slightly lower than the theoretical values. The mode amplitude obviously increases with increase in NBI power, and reaches up to $\tilde{B}_\theta/B\sim 3\times10^{-5}$. Moreover, the modes are not observed in ECH plasma. After NBI switching off the modes decay faster than the usual pressure driven mode as shown in Fig. 3.

TAE gap positions may be predicted for a cylindrical geometry, where the electron density profile measured by Thomson scattering and the rotational transform profile calculated with the 3D equilibrium

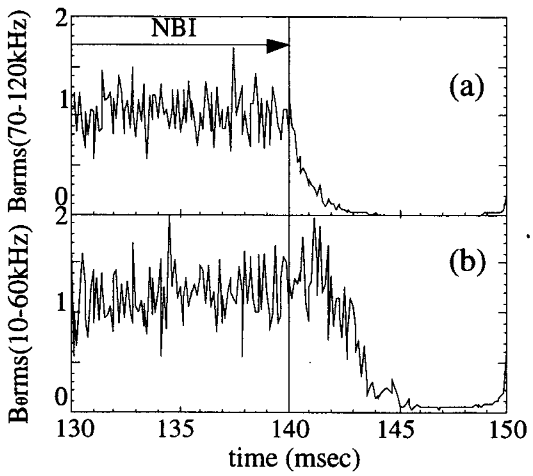

Fig. 3 Time behavior of root-mean squared (rms.) amplitude of the coherent mode (a) and usual pressure driven modes (b) after switching NBI off.

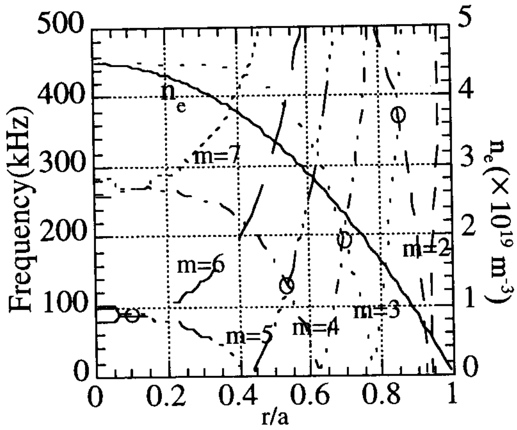

Fig. 4 Alfvén continua for various poloidal number m, for toroidal mode number n=2. A circle denotes the TAE gap.

VMEC code are employed (Fig. 4). The toroidal mode number of the modes in this shot is predicted to be $n \geqq 2$ with the magnetic probes arranged in the toroidal direction. The frequency of the calculated TAE gap near the center of the plasma ($r/a \sim 0.1$) is close to the observed mode frequency. From soft X-ray data, the gap position is predicted to be near the plasma center ($r/a < 0.2$).

An approximate expression for the local growth rate of TAE instability is [5]

$$\gamma/\omega \sim 9/4[\beta_f(\omega_{*f}/\omega - 1/2)F - \beta_e V_A/V_e)] \quad (1)$$

where β_f, β_e, ω_{*f}, V_e are the fast ion and electron betas, fast ion diamagnetic frequency and electron thermal velocity, respectively. The angler frequency ω is TAE frequency and $F = x(1 + 2x^2 + 2x^4)/\exp(-x^2)$ with $x = V_A/V_b$, V_b is the average beam particle velocity. For our experimental conditions, the ratio V_b/V_A is $0.35 \sim 0.9$ and $\omega_{*f}/\omega > 1$. Eq. (1) suggests the possibility of excitations of the TAE modes in CHS. However, other important damping mechanisms should be taken in account such as beam ion Landau damping, continuum damping so on.

3. Summary

In CHS, magnetic fluctuations with relatively high frequency are observed. The frequency of observed magnetic fluctuations is consistent with the frequency of the calculated TAE gap near the plasma center for measured toroidal mode number. The observed magnetic fluctuations in the TAE frequency range are thought to be the TAE modes driven by energetic ions of NBI. Further studies are required to clarify detailed parameter range of the excitation, internal structure and effects on energetic ion transport.

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